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Compact resonantly intra-cavity pumped tunable Ho:Sc_2SiO_5 laser

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HIGHLIGHTS

- We report a low-threshold intra-cavity pumped continuous-wave Ho:SSO laser is realized, and a tunable output wavelength is demonstrated by using a birefringent filter in the laser resonant cavity.
- A wavelength tunable range of 140 nm from 2020 nm to 2160 nm is achieved.

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ABSTRACT

A compact intra-cavity pumped low threshold continuous-wave Ho:Sc_2SiO_5 laser is reported. The characteristics of output wavelength tuning are investigated by use a intra-cavity briefringent (BF) filter. A wavelength tunable range of 140 nm from 2020 to 2160 nm is achieved. For the free-running mode, the laser slope efficiency is 24.8%, when the output central wavelength is 2110 nm. The laser threshold is about 820 mW of incident pump power. With the BF filter, a maximum output power of 870 mW is obtained at the incident pump power of 5 W, corresponding to a slope efficiency of 20.3%. The characteristics of output wavelength verse the crystal temperature are also investigated.

1. Introduction

The 2 μm lasers are in the eye-safety wavelength regions, and include strong absorption lines of water and weak absorption lines of atmosphere. Therefore, it is expected to have potential applications in wide range of fields, such as atmospheric remote sensing which include Doppler radar wind sensing and water vapour profiling by differential absorption radar, spectroscopy and basic research. Furthermore, high-power quasi-continuous wave (QCW) 2 μm lasers with high peak power are effective pump sources of optical parametrical oscillators and solid-state lasers further in the mid-infrared region [1–3]. Tm and Ho co-doped media with large emission cross section can meet the requirement of generation high peak power laser pulse, but they must be cooled to lower temperature suffering from more high up-conversion effects and energy transferring between Tm and Ho [4,5].

One way to alleviate these effects is to make Ho and Tm in separate crystals. With the quickly development of high power 1.9 μm laser as an efficient pump source [6], the 2 μm lasers based on Ho-doped crystals have becomeprominent in these applications, and the host materials for these Ho lasers are usually $Y_3Al_5O_{12}$ (YAG), $LiYF_4$ (YLF). The most attractive Ho-doped lasers are the Ho:YAG and Ho:YLF lasers, which have higher efficiency and higher power than other Ho-doped lasers [7,8]. But the emission spectrum of Ho:YAG and Ho:YLF are very narrow, which limits the applications for the 2 μm lasers. Such as the gas detection and 2 μm ultra-short pulse lasers. The Ho laser system pumped by a Tm laser is very complex, which needs a lot of mirrors to achieve the 2 μm laser output [9]. Sometime the complex system is not suitable for the applications. So we can put the Tm-doped crystal and the Ho-doped crystal into one common laser cavity to make the laser system more compact. The laser system can operate with only one laser cavity pumped by a LD [10].

In this letter, Holmium-doped Sc_2SiO_5 (SSO) is chosen as a 2 μm laser gain medium to achieve output wavelength tuning. For the Ho:SSO crystal, the change of the refractive index with temperature dn/dT (the derivative of the refractive index with temperature) is a negative amount [11], which can limit the thermal lens effects, crystallographic sites distortion and birefringent effects. The SSO crystal is a monoclinic crystal with low symmetry, where the Sc(I) and Sc(II) case are both six coordination. The Ho^{3+} doped into the SSO crystal has a strong field coupling characteristics, which can reduce the population of the lower energy level as well as increase the energy level spitting. The energy level splitting

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reaches 712 cm^{-1}. The strong field coupling characteristics broaden and smooth the emission spectrum of Ho:SSO, whose full width at half maximum (FWHM) is 193 nm. Up to the authors' knowledge, it is the widest emission spectrum among the Ho-doped crystals. With a intra-cavity briefringent filter, a tunable Ho:SSO laser pumped by a Tm:YAP laser is realized, which has a tunable range of 140 nm from 2020 nm to 2160 nm (Fig. 1).

2. Experimental setup

The experimental setup is schematically shown in Fig. 2, in which a simple L-shaped plane-concave cavity. The pump source is a diode laser (Nlight Canada; P2-030; FWHM: 1.4 nm). with a 200 μm core-diameter pigtail fiber, whose maximum output power is 30 W at the center wavelength of 793.2 nm. The waist radius of the pump beam in the cavity is about 100 μm. The pump beam was focused into a spot of 130 μm in diameter around the Tm:YAP and Ho:SSO crystal. The dichroic mirror M_1 is a plat mirror with HR coated at 1.9–2.3 μm and high-transmission (HT) coated at 793 nm. The mirror M_2 is also a plat mirror, which is coated HR at 1.9 μm–2.3 μm and HT at 793 nm. M_3 serves as an output coupler, which is a concave mirror with curvature radius of 100 mm. The output coupler has a transmissions of 1% at 2–2.3 μm and a high transmission at 1.94 μm. The output wavelength tuning is realized by a briefringent filter inserted into the laser resonant cavity, which is a 3 mm-thick quartz plate with the optical axis parallel to the plate faces. The Tm:YAP crystal doped with 4 at.%, has a dimension of 3 mm × mm (in section) × 8 mm (in length). Both end faces of crystal are anti-reflection (AR) coated at 793 nm, 1.9–2.3 μm. The Ho:SSO crystal doped with 0.5 at.%, has a dimension of 3 mm × 3 mm (in section) × 10 mm (in length). Both end faces of crystal are anti-reflection (AR) coated at 1.9–2.3 μm. Both the Tm:YAP and Ho:SSO crystal are wrapped in indium foil and held in a copper heat-sink bonded on a thermal electric cooler (TEC) for precise temperature control.

3. Experimental results

Fig. 2 shows the characteristics of output slope efficiency verse the crystal temperature. In the experiment, a power meter (Coherent USA; Power Max PS19) was used to measure the output power of the Ho:SSO laser. From the figure we can conclude that, the laser slope efficiency increases with the decline of crystal temperature. We can realize a more efficient laser operation by keeping the laser crystal at a lower temperature. The length of laser cavity is also significant to the laser slope efficiency. The output slope efficiency with different laser cavity length (L) is investigated also. We can conclude that from the Fig. 2, we can realize a higher efficiency by a compact laser cavity.

Fig. 3 shows the output characteristics of Ho:SSO lasers, when the temperature of laser crystals are 15 °C. For the free-running mode, the laser slope efficiency is 24.8%, when the output central wavelength is 2110 nm. The laser threshold is about 820 mW of incident pump power. With the BF filter in, the laser slope efficiency is a little lower to 20.3% due to the additional loss. The laser threshold increases to 930 mW.

Fig. 4 shows the tunability curve with 5 W incident pumping power, when the transmissions of output mirror is 1% at 2 μm. The output spectrum of Ho:SSO laser are recorded by a 300 mm focal length WDM1–3 monochromator with a 600 lines/mm grating blazed for 2 μm, a locked-in amplifier (Stanford USA; SRS830)

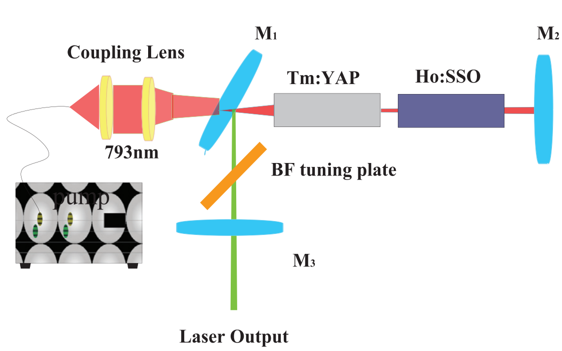

Fig. 1. Schematic diagram for the intra-cavity pumped Ho:SSO laser.

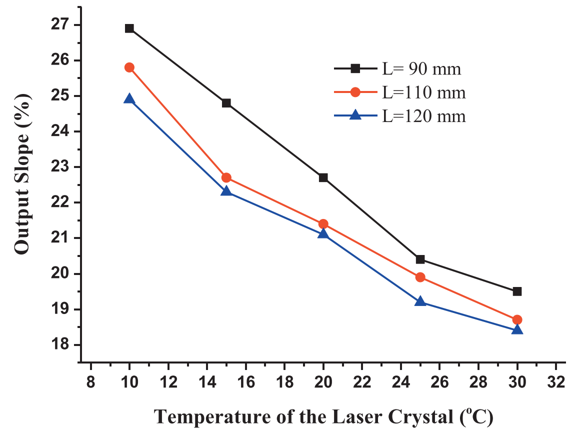

Fig. 2. The characteristics of output slope efficiency verse the crystal temperature with different length of the laser cavity.

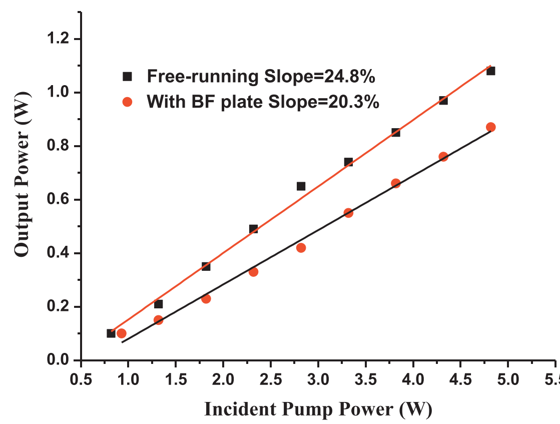

Fig. 3. Output power of the Ho:SSO laser.

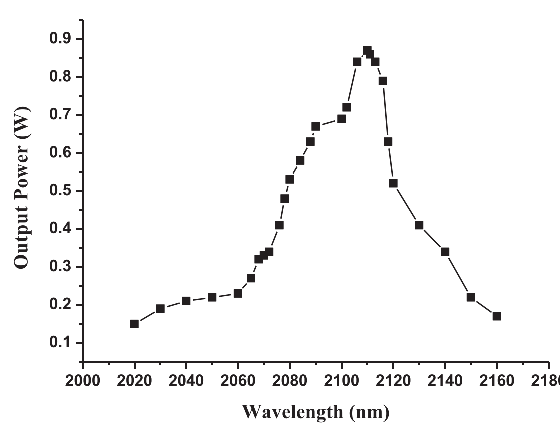

Fig. 4. Tunability curve of the Ho:SSO laser.

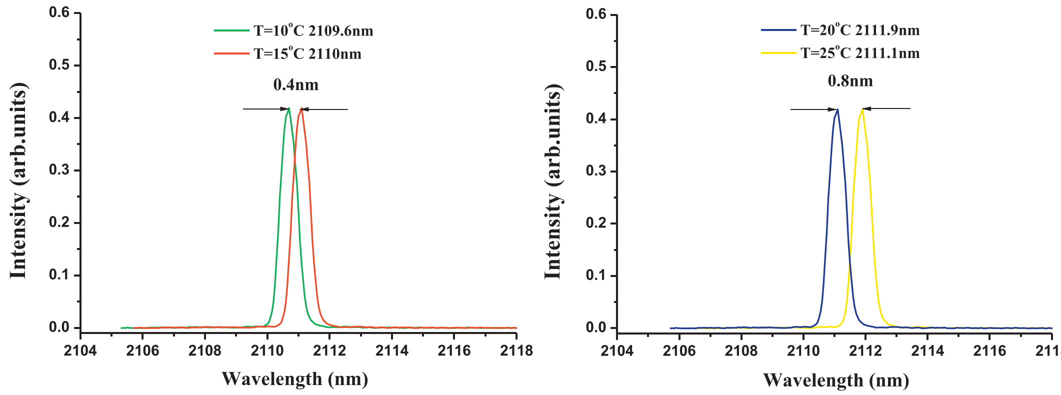

Fig. 5. The output wavelength of the Ho:SSO laser at different temperature.

was used to improve the signal-to-noise ratio. A tunable range of 140 nm from 2020 nm to 2160 nm is realized. The maximum output power reaches 870 mW at 2110 nm. The transmissions of the output mirror is 1% from 2000 nm to 2300 nm. The transmittance increases sharply when the wavelength shorter than 2000 nm, the laser can't start up in the resonant cavity. So we only tuned the output wavelength to 2020 nm. From the emission spectrum of Ho:SSO, there is little emission longer than 2160 nm.

Fig. 5 shows the output wavelength at different crystal temperature. We use the thermal electric cooler (TEC) to control the crystal temperature, and record the output wavelength by the monochromator combined with the locked-in amplifier aiming to improve the signal-to-noise ratio. We can conclude that from Fig. 5, the output wavelength is relative to the crystal temperature. We can realize the output wavelength shift by changing the laser crystal temperature.

4. Conclusion

In summary, low-threshold intra-cavity pumped continuous-wave Ho:SSO laser is realized, and a tunable output wavelength is demonstrated by using a birefringent filter in the laser resonant cavity. A wavelength tunable range of 140 nm from 2020 nm to 2160 nm is achieved. For the free-running mode, the laser slope efficiency is 24.8%, when the output central wavelength is 2110 nm. The laser threshold is about 820 mW of the incident pump power. With the BF filter, a maximum output power of 870 mW is obtained at the incident pump power of 5 W, corresponding to a slope efficiency of 20.3%. The characteristics of output wavelength verse the crystal temperature is also investigated.

Conflict of interest

None.

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References

[1] M. Gower, Industrial applications of laser micromachining, Opt. Express 7 (2) (2000) 56–62.
[2] Z.X. Jiao, G.Y. He, J. Guo, B. Wang, High average power 2 μm generation using an intracavity PPLN optical parametric oscillator, Opt. Lett. 37 (1) (2012) 64–68.
[3] M. Schellhorn, A. Hirth, Modeling of intracavity-pumped quasi-three- level lasers, IEEE J. Quantum Electron. 38 (11) (2002) 1455–1459.
[4] G. Galzerano, M. Marano, S. Longhi, E. Sani, A. Toncelli, M. Tonelli, P. Laporta, Sub-100-ps amplitude-modulation mode-locked Tm–Ho:BaY_2F_8 laser at 2.06 μm, Opt. Lett. 28 (21) (2003) 2085–2087.
[5] W. He, B. Yao, Y. Ju, Y. Wang, Diode-pumped efficient Tm, Ho:$GdVO_4$ laser with near-diffraction limited beam quality, Opt. Express 14 (24) (2006) 11653–11659.
[6] Y.L. Lu, Y.B. Dai, Y. Yang, J. Wang, A.P. Dong, B. Sun, Anisotropy of thermal and spectral characteristics in Tm:YAP laser crystals, J. Alloys Compd. 453 (1–2) (2008) 482–486.
[7] Z. Cui, X.M. Duan, B.Q. Yao, H.Y. Yang, J.H. Yuan, C.L. Zhang, T.Y. Dai, Actively mode-locked Ho:LuAG laser at 2.1 μm, Appl. Phys. B 121 (4) (2015) 421–424.
[8] R.C. Stoneman, L. Esterowitz, Intracavity-pumped 2.09-μm Ho:YAG laser, Opt. Lett. 17 (10) (1992) 736–738.
[9] Kenneth L. Schepler, Brian D. Smith, Frank Heine, Guenter Huber, Passive Q-switching and mode locking of 2-μm lasers, Proc. SPIE 1864 (1993) 186–194.
[10] C. Bollig, R.A. Hayward, W.A. Clarkson, D.C. Hanna, 2-W Ho:YAG laser intracavity pumped by a diode-pumped Tm:YAG laser, Opt. Lett. 23 (22) (1998) 1757–1779.
[11] X.T. Yang, B.Q. Yao, Y. Ding, X. Li, G. Aka, L.H. Zheng, J. Xu, Spectral properties and laser performance of Ho:Sc_2SiO_5 crystal at room temperature, Opt. Express 21 (26) (2013) 32566–32571.